Stability and acoustics

There were three projects in this group, all of which investigated the utility of analytical tools in conjunction with advanced flow simulations. The first investigated by-pass transition mechanisms in boundary layers, which are important in numerous aerodynamics applications. It is well known that boundary layers rarely transition to turbulence via a saturation of their most unstable linear modes (Tollmien-Schlichting waves); by-pass transition refers to any other mechanism leading to nonlinear saturation and turbulence. Visitor P. Ricco and hosts P. Durbin and T. Zaki worked to evaluate and extend the Boundary Region Theory of Lieb, Wundrow & Goldstein to describe a nonlinear by-pass transition mechanism involving receptivity to a free-stream mode. They found that the linear Boundary Region Theory concurs with Orr-Sommerfeld theory concerning which modes can efficiently penetrate the boundary layer, suggesting that inclusion of non-parallel flow effects is not crucial in models. They have also developed a nonlinear formulation of this theory to study two-mode interactions, which Durbin & Zaki have suggested to be important in by-pass transition.

The second project was an application of a new general flow-field decomposition—the multiscale window transform—which has certain attractive properties. It employs special basis functions that allow the energy in user selected nominal scales of an inhomogeneous flow to be unambiguously defined. This property then allows one to define the transfer of energy between these scales, the control of which is often the target of flow control applications. For drag control, for example, extraction of energy from the mean by large-scale turbulence should be suppressed. In this project, visitor X. S. Liang, who developed the multiscale window transform, worked with host M. Wang to make a precise designation of this inter-scale transfer in the wake of a circular cylinder. They defined scales corresponding to the mean flow and largest turbulence structures and identified locations of high energy transfer between these scales. These are thought to correspond to the most effective points at which to apply control in order to disrupt this transfer.

The final project was motivated by the prediction of jet noise, which is an important problem facing aircraft and engine makers. To do this, one typically defines a noise source, which is modeled using turbulence theory, and a wave propagation operator, which is inverted to computed the radiated noise. Unfortunately, since sound perturbations cannot be decoupled from other fluctuations in a compressible turbulent flow, there is no unique decomposition of the flow into a noise source and inhomogeneous wave equation. Many such formulations have been proposed over the last fifty years, but since all are exact consequences of the flow equations, it is hard to demonstrate clearly why one might be better than another. J. B. Freund and S. K. Lele addressed this issue in a new way using DNS data by evaluating the robustness of different formulations to errors intentionally introduced into the noise sources. They found a clear differences in the performance for different formulations.

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